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2021 Volume IV: The Earth’s Greenhouse and Global Warming

The Impact of Ocean Acidification on Marine Ecosystems

Curriculum Unit 21.04.01
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We have been hearing about the phenomena of Global Warming, Ocean Acidification, and troubled marine ecosystems in the news lately. In what way are all of these three connected? How does global warming contribute to the bleaching of the corals that are located on the ocean floor? This unit will shed some light on the process of how carbon dioxide (CO_2) produced by the carbon cycle combined with human activities results in the formation of atmospheric CO_2. Some of the excess from fossil fuel burning get absorbed by the oceans resulting in a drop in the pH and makes the water acidic. In turn, the acidity of the oceans is negatively affecting the soft shell formation of some marine animals, including corals. Some of the devastating effects include threat to the survival of marine plants and animals, bleaching of corals, weaker shell formation in some invertebrates, and the extinction of the marine ecosystems, resulting in the decrease of ocean biodiversity across the globe.

I teach biology at one of the largest comprehensive high schools in New Haven, Connecticut. Biology is a mandatory, sophomore science class that is required for graduation. This unit is designed for 10th-grade biology students. This curricular unit is designed with the Next Generation Science Standards (NGSS) in mind. The State of Connecticut adopted the NGSS[1] in 2015 and the unit will allow the instructor to weave many of the NGSS practices into classroom activities for the students. This unit will highlight several of the national standards from chemistry, life science, physical science, environmental science, and engineering.

The current 10th-grade biology curriculum is partially aligned with the NGSS. For example, during the third marking period the curriculum expects that the students will be able to:

understand the basics of ecology, the structure of various ecosystems, the interdependence of organisms in an ecosystem, and the importance of biodiversity in the survival of these ecosystems. However, the current curriculum fails to expose the students to the importance of the impacts of human activities on ecosystems, basic understanding of the carbon cycle, ocean acidification, and its effects on plants and animals that make up the marine ecosystems. This is the main reason why this unit was developed. This unit has the potential to create awareness among the younger generations about these phenomena.

The high school where the author teaches utilizes a block schedule wherein students attend four classes per day, each running for about 90 minutes. Students have eight classes total and any given class meets either 2 or 3 times per week. This presents challenges for teachers concerning homework and turn-around time for feedback because of long gaps between class meetings. The block schedule offers a longer class period wherein lab experiments are more easily carried out. The unit will be taught during the third marking period when students learn ecology. This 2-week unit could be modified for K-8th grade level students. Therefore, the unit has the potential to fill gaps in the current biology curriculum.

Rationale and Purpose of the Study

This unit is designed to provide the reader with an understanding of the carbon cycle, reasons why the CO_2 levels are going up in the atmosphere, how this increase impacts pH in the ocean waters, and how lower pH or ocean acidification impacts the plants and animals that make up the marine ecosystems. Students will have a chance to understand the major players in these processes and will be provided with opportunities to create models to better understand as well as visualize these concepts. This unit also includes several demonstrations revolving around the concepts of the carbon cycle, ocean acidification, and its impact on soft-shell forming organisms, plants, and corals. Giving students several opportunities to understand the concepts and later come up with strategies that will help understand, mitigate, decrease, and maybe even reverse the stresses caused by ocean acidification.

As a culminating activity, the students will create awareness posters to inform and enlighten their classmates, family, and community members about the negative impacts of ocean acidification. They will also write letters to their local representatives about the possible laws and practices that could be set in place to address these issues in their communities. This two-week unit (5 blocks 90 minutes long) is designed to understand the phenomena of the carbon cycle, ocean acidification, and its effects on plants, animals that make up the marine ecosystems. The unit is designed while keeping 10th grade, inner-city, high school students in mind.

Next Generation Science Standards (NGSS), state, and district standards addressed: The Next Generation Science Standards (NGSS) high school life science curriculum consists of five topics: 1) structure and function, 2) inheritance and variation of traits, matter, and energy in organisms and ecosystems, 4) interdependent relationships in ecosystems, and 5) natural selection and evolution. This unit covers a part of the structure and function as well as the interdependent relationships in ecosystems particularly, the marine ecosystems and the impact of human activities on their survivability. Students demonstrate their understanding through critical reading, using models, and conducting investigations.

The National Standards that are covered through this unit include:

- HS-LS2: Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.
- HS-ESS 2-6: Develop a quantitative model to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.
- NGSS-HS-ETS1-2. Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

This unit will incorporate the following Next Generation Science Standards (NGSS) Science and Engineering Practices[2] :

- Asking questions (for science) to understand the carbon cycle, how the increase in atmospheric CO_2 impacts the pH of ocean waters, and how lower pH might impact the ocean life
- Developing and using models to understand the process of ocean acidification and how lowering the pH affects the marine ecosystem
- Constructing explanations (for science) about the ocean acidification negatively impacts the plants, animals that make up the marine ecosystem
- Obtaining, evaluating, and communicating information about the impact of human activities such as the burning of fossil fuels and increasing the CO_2 concentration in the atmosphere cause ocean acidification.

Research Questions

The research questions that this unit is going to focus on are:

1. What is the carbon cycle? Create a model to understand the major players of this cycle.
2. What is ocean acidification and how is it caused?
3. Identify the stresses ocean acidification places on ocean life.
4. Understand how ocean acidification impacts plants, animals, and the marine ecosystem.
5. Identify practices that could be set in place to create awareness about how human activities such as the burning of fossil fuels negatively impact on the marine ecosystems.

Content Objectives

The main content objectives covered in this unit are the phenomena of global warming, carbon cycle, ocean acidification, and its impact on plants, animals, and the marine ecosystem. The main purpose of this is to provide the reader with the basic knowledge base about these processes and understand the main players that are responsible for them. Fossil fuel pollution by human activities is contributing to the increase in the amount of CO_2 in the atmosphere. Some of the CO_2 is being absorbed by the oceans. This process increases the number of free hydrogen ions in the oceans, making the ocean water more acidic. This phenomenon is called ocean acidification. When oceans become acidic, they can negatively affect the plants, living organisms such as shell-forming organisms, and other marine life. The results of this process are devastating and this unit hopes to bring students' attention to these dangers.

Global Warming

Global warming[3] has been causing global temperatures to rise at higher levels and also causing severe climate changes across the planet. According to an article published in Scientific American[4] , if unchecked, global warming could increase the average temperature of the United States by 10ºF (Fahrenheit) over the next century. Global warming is caused due to the emission of greenhouse gases. These greenhouse gases trap heat in the atmosphere resulting in the warming of the planet. This process is called the greenhouse effect. The gases responsible for causing this greenhouse effect are CO_2, water vapor, methane, ozone, nitrous oxide, and chlorofluorocarbons (CFC)[5] .

According to the Environmental Protection Agency (EPA)[6] , greenhouse emissions caused by human activities also referred to as non-anthropogenic) such as the burning of fossil fuels have been steadily increasing in the United States and across the world. Similarly, the majority of the world's emissions result from the generation of electricity, transportation, and other forms of energy production and usage. Carbon dioxide is emitted primarily through the burning of fossil fuels (oil, natural gas, and coal) and deforestation. According to the Global Carbon Project[7] , the top five countries that produce carbon dioxide (CO_2) emissions from burning fossil fuels are China, U.S.A, India, Russian Federation, and Japan. Other sources that also contribute to global warming are Nitrous dioxide (N_2O) released through fertilizer usage, methane emitted through the raising of the cattle, harvesting of fossil fuels. Chlorofluorocarbons (CFCs) are a group of gases that do not occur naturally, are produced during commercials, industrial, and household uses, and are known for their ozone-depleting properties. In summary, the combustion of fossil fuels contributes to emissions of CO_2, methane, and nitrous dioxide gases.

The Keeling Curve[8] depicts the concentrations of CO_2 at Mauna Loa Observatory located in Hawaii. In 1958, Charles David Keeling of Scripps Institution of Oceanography, UC San Diego, worked with scientists to create a method to record carbon dioxide (CO_2) in our atmosphere. The measurements of CO_2 in the atmosphere are due to the impact of human activities on the planet. According to scientists, there is a direct correlation between the burning of fossil fuels, rising CO_2 levels, and the warming of the planet. The figure-1 shows the CO_2 concentration (ppm) recorded on May 18, 2021. One can see a steady increase in CO_2 levels from 1960 to date. This increase in the levels of CO_2 is alarming to the scientific community. A quarter of the CO_2 thus emitted into the atmosphere is being absorbed by the oceans, rivers, and lakes. This unit will focus on the impact of CO_2 on ocean waters.

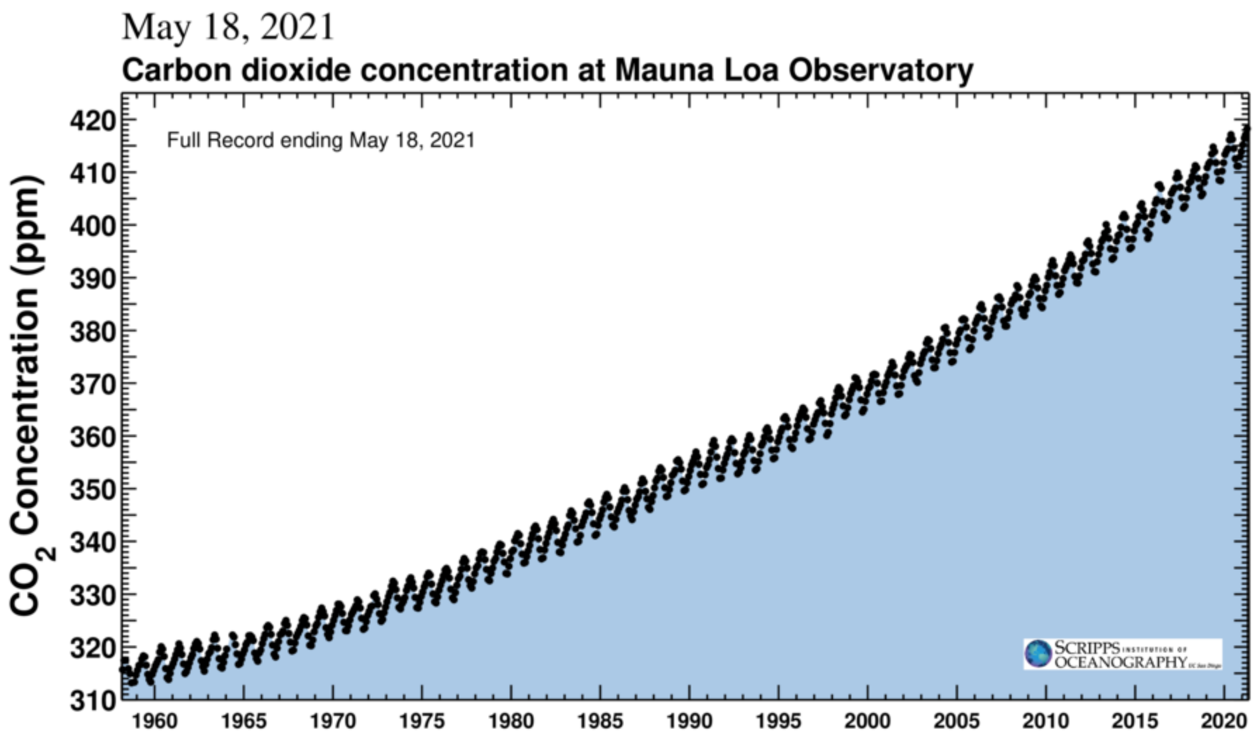

Figure-1: The Keeling Curve depicts the measurement of CO_2 *at Mauna Loa Observatory.*

Carbon and Carbon Cycle

Carbon (from Latin *carbo* means coal) is a chemical element with the symbol C and atomic number 6. Carbon is the foundation of life and carbon compounds form the backbone of all living organisms on Earth. Carbon is the building block that is required to form biomacromolecules such as carbohydrates, proteins, lipids, and nucleic acids[9] . The carbon cycle[10] is a biogeochemical cycle. It describes the process through which carbon molecules travel from the atmosphere to terrestrial biomes and the ocean and then back to the atmosphere. For example, carbon is everywhere, in the rocks, living organisms, sediments in the ocean, and the atmosphere. In this manner, carbon constantly transfers between oceans, the soil, and the atmosphere over centuries. The five major carbon reservoirs are rock, atmosphere, oceans, terrestrial biosphere, and fossil fuels. Figure-2[11] explains the details about the carbon reservoirs and how carbon moves between them. So, carbon moves from one reservoir into another through a variety of mechanisms such as photosynthesis, respiration, ocean gas exchange, human activities, and so forth.

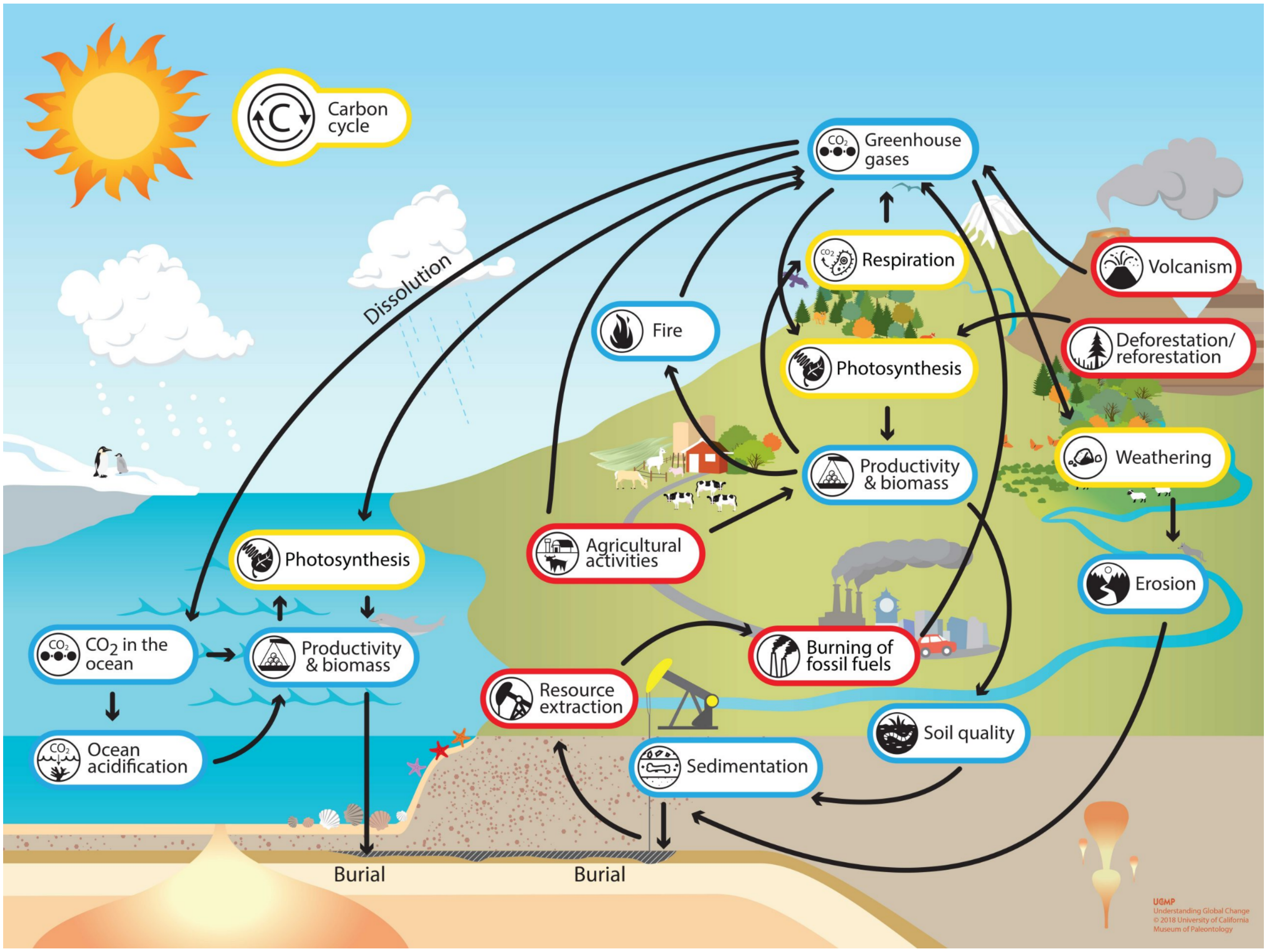

Figure 2: Carbon Cycle (adopted from Understanding Global Change, Copyright © 2016, UC Museum of Paleontology, ugc.berkeley.edu)

Plants fix carbon during the process of photosynthesis and make glucose which is sugar. When herbivores eat the plants, they use glucose and other organic molecules to produce energy through the process of cellular respiration. One of the by-products of this is CO_2 which is breathed out during respiration. We can refer back to the Keeling Curve (Figure-1) and see the breathing of the planet. For example, due to the increase in primary productivity during the growing season, the plants and trees are taking in more CO_2 and in the process leading to the lows in the summer. On the other hand, the decrease primary productivity along with cellular respiration leads to highs in the winter. When organisms die and decay some of the CO_2 is released into the atmosphere and some of it becomes a part of the soil. When fossil fuels are burned huge amounts of CO_2 are released into the atmosphere. Humans play a major role in the carbon cycle through activities such as the burning of fossil fuels, land development, and the destruction of trees. Therefore, the above-mentioned processes are referred to as the sources of CO_2. Plants, trees, blue-green algae, and other photosynthetic organisms fix carbon through the process of photosynthesis and produce glucose and other sugars, and the chemical weathering of rock minerals removes the CO_2. This is why these processes are referred to as sinks of CO_2. Thus the movement of carbon in the form of CO_2 could be traced from the atmosphere to plants, to herbivores, to carnivores, and back to into the atmosphere.

Other sources that result in adding CO_2 to the atmosphere include forest fires, deforestation, volcanic eruptions, agricultural activities, burning of fossil fuels, and formation of CaCO3. Figure-2 explains the carbon cycle and the movement of carbon between the atmosphere, land, plants, animals, and the oceans. Human activity, especially the burning of fossil fuels, changing land use, and the production of limestone to make concrete are some of the major contributors of CO_2 to the atmosphere. Fossil fuels include coal and oils which are storage reservoirs of carbon from plant matter and animals that lived centuries ago. The rate at which the levels of CO_2 are increasing is very alarming[12] . Scientists also warn that the increase in CO_2 due to the burning of fossil fuels could affect our climate for hundreds of years.

Carbonate System and Ocean Acidification

The uptake of anthropogenic atmospheric carbon dioxide (caused or influenced due to human activity) is changing the ocean's chemistry[13] . pH is a measure of how acidic or basic the water is. It is also a measure of the amount of free hydrogen and hydroxyl ions in water. The pH scale ranges from 1-14, where 7 is considered neutral, anything lower than 7 is acidic and more than 7 is basic or alkaline. Acidity is a measure of the concentration of free hydrogen ions (H+) in a water-based solution. So, the increase in free hydrogen ions (H+) causes high acidity or lower pH. One needs to understand that addition of $CO_{2.}$ decreases the pH of the ocean waters. On the other hand, the removal of $CO_{2.}$ increases the pH of ocean waters. This decrease in the pH makes the ocean water acidic. This phenomenon is called ocean acidification (OA). This process is slowing down the marine animals from making the skeletons and shells and is also negatively affecting the plants, animals, coral reefs, and the entire marine ecosystem.

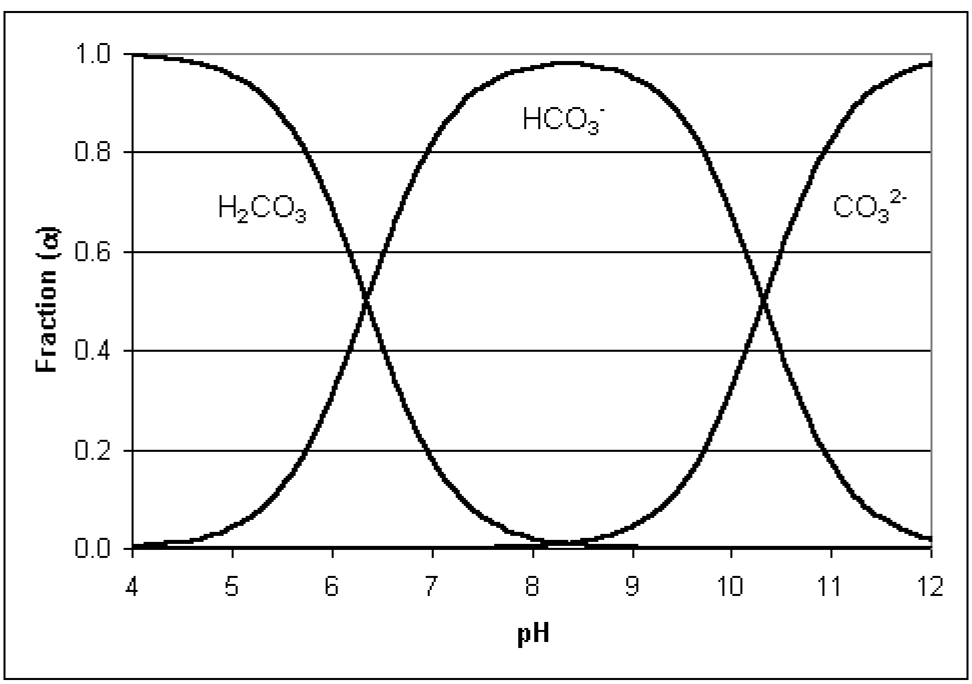

Figure 3: Ionization fraction plot of CO_2

The Revelle Factor (buffer factor) is a measure of the "oceans buffer capacity for the carbonate system in sea water and fresh water”[14] . It is also a good indicator of the oceans pH levels. With the increase in the absorption of the anthropogenic CO_2. Figure-3 explains the ionization factor (▯) of CO_2 and how it affects the ocean pH. It is also a good indicator of the pH levels of ocean water. The process of ocean acidification (OA) is complicated and could be explained as follows (see Figure-4). It starts with the absorption of anthropogenic carbon dioxide (CO_2) from the atmosphere by the ocean. This increases the dissolved inorganic carbon concentration (DIC) at the surface of the ocean waters. Thus the accumulation of atmospheric CO_2 causes the following changes in the ocean water chemistry. First, the CO_2 gas is converted into CO_2 (aq)[15] . The CO_2(aq) can also dissolve limestone, which is a sedimentary rock made up of calcium carbonate ($CaCO_3$)[16] . Many marine animals also use calcium carbonate ($CaCO_3$) to make their shells, exoskeletons, and other structures. Next, the CO_2(aq) reacts with water to form carbonic acid (H_2CO_3) which is a weak acid. The carbonic acid (H_2CO_3) makes the ocean waters slightly acidic by increasing the number of free hydrogen ions (H+). Then the carbonic acid (H_2CO_3) thus formed can dissociate into bicarbonate (HCO_3-) and free hydrogen ions (H+). Lastly, the bicarbonate (HCO_3-) can further dissociate into carbonate ions (CO_3^{-2}) and more free hydrogen ions(H+). The above reactions are all reversible, meaning, they can also take place in the opposite direction (represented by arrows pointing in both directions) thus changing the chemistry of the surface waters of the ocean. Given that most marine organisms live in the upper waters of the ocean, these above changes in the chemistry of the water have devastating effects on the daily survival of these organisms.

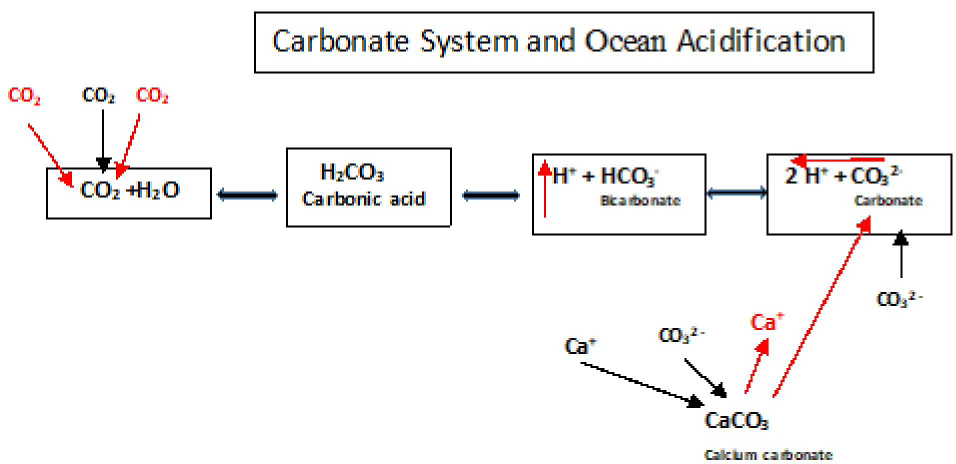

Figure-4: Carbonate System and Ocean Acidification (Adapted from graphics created by Chris Gobler, Stony Brook University)

According to the United States Environmental Protection Agency (EPA)[17] , during the pre-industrial times the average pH of the oceans was approximately 8.2 and today the average pH is around 8.1. Given that the pH scale is logarithmic. Thus decrease in one unit of pH represents approximately a 10 fold increase in the acidity of the ocean waters. CO_2 forms a weak acid in water know as carbonic acid (H_2CO_3). That said, the increase in the absorption of anthropogenic CO_2(sink) from the atmosphere into the oceans is resulting in the decreasing pH of the oceans. The scientific community is alarmed that the atmospheric CO_2 has increased 40% higher than the pre-industrial time and the current ocean acidity, on average, is roughly 25% higher than what it was during the pre-industrial times.

According to scientists, approximately 26 percent of all the anthropogenic CO_2 released from human activities such as burning fossil fuels, changes made to the landmasses, cement production, so forth is being absorbed by the oceans. This process has been intensifying since the beginning of the Industrial Revolution in 1760. According to the Global Carbon Project[18] , fossil fuel burning account for approximately 35 billion tons of CO_2 produced, and deforestation in the tropics adds roughly 5.5 billion tons which are some of the sources of CO_2. Out of the CO_2 thus produced, only half stays in the atmosphere causing global warming, while a quarter of it is taken up by plants and trees and the other quarter is absorbed by the oceans. Research studies stress that the oceans can hold up to 50 times more carbon than the atmosphere. As the concentration of CO_2 in the atmosphere increases, so does its absorption by the oceans. This process is disrupting the chemical balance of ocean waters.

Metaphorically, some of the negative effects of ocean acidification[19] are referred to as the Osteoporosis of the Sea[20] . According to medical professionals, osteoporosis (porous bone)[21] is a bone disease where the human body loses too much or makes too little bone. This process weakens the bones and makes the body prone to accidents and injuries. This condition results in a fragile skeletal system and creates pores or honeycomb-like structures in the bones. It also decreases bone density, which makes the bones fragile and easy to break. In the same fashion, ocean acidification is negatively affecting the shell and skeleton formation of marine plants and animals. Marine animals need carbonate and calcium to form their shells. Thus the addition of the anthropogenic $CO_2$to the ocean waters is decreasing the carbonate concentrations. Therefore, the process of ocean acidification is decreasing the availability of carbonate, slowing down the process of shell formation, and dissolving the existing shells. The decreasing rate of shell formation and increasing rate of shell dissolution is therefore threatening the existence of marine ecosystems.

Current research stresses that the ocean surface temperature is rising. The main culprits include: global warming, the decrease in the mixing of the ocean waters, the oceans inability to pump the excess carbon from the surface to the deeper layers of the ocean, and the diminishing growth of the Phyto (plant) plankton (made to wander or drift) which are the foundation of the marine food webs[22] are contributing to the increase in the ocean surface temperatures. This increase in the ocean temperature[23] is negatively affecting the health of marine ecosystems. It is one of the major causes of coral bleaching. When corals undergo stress due to changes in temperature, light, and lack of nutrients they expel the symbiotic algae that inhabit their tissues. This process turns the beautifully colored corals white, hence the term coral bleaching[24] . The coral bleaching negatively affects the marine organisms such as fish that build their nurseries in these reefs, organisms that hide from their prey, decrease in revenue for tourism for some areas, and loss of diversity in the marine ecosystems. Figure-5 shows the journey of atmospheric CO_2 from the atmosphere into the ocean waters causing ocean acidification, its impact on the shell formation of some marine animals, and how this process is devastating the entire marine ecosystem.

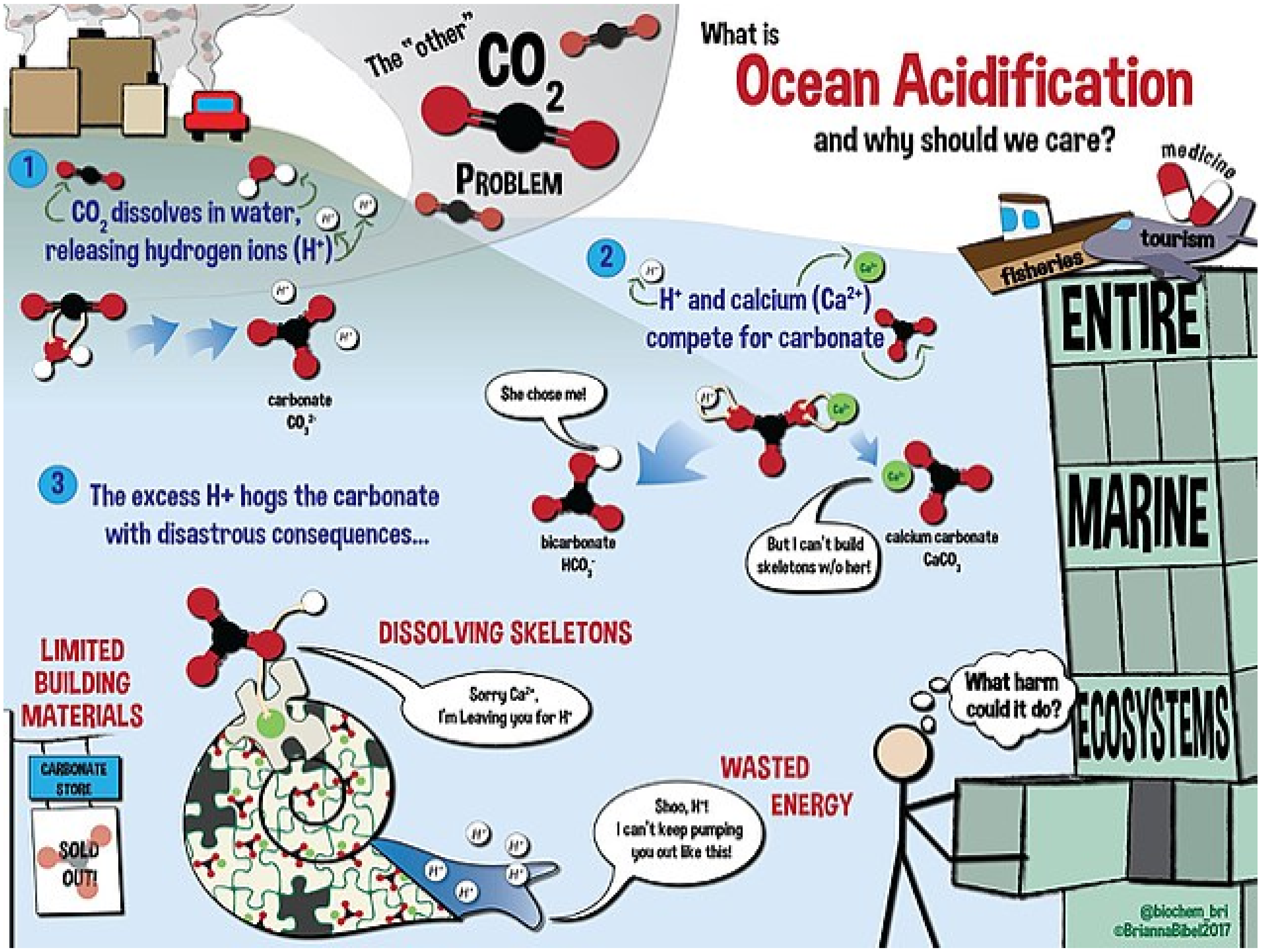

Figure 5: This infographic explains ocean acidification and its impact on the entire marine ecosystem. Adapted from Wikimedia Commons (public domain)

Effect of ocean acidification on primary productivity: The process of ocean acidification negatively affects the entire marine ecosystem. For starters, algae and other photosynthetic organisms in the ocean undergo photosynthesis and store the organic carbon in their tissues. These organisms are the producers and form the bottom foundation of the food pyramid. The phytoplankton (free-floating plants)[25] are consumed by zooplankton (pteropods) which are a major source of food for salmon, mackerel, herring, cod, and even whales. Organisms such as pteropods[26] which are food sources for krill are having their shells dissolved due to ocean acidification. The krill are the main food source for whales. The consumers also undergo cellular respiration, use sugar to produce energy, and release carbon dioxide (CO_2) into the ocean waters. When the phytoplankton dies, the carbon that is part of their tissues sinks to the bottom of the ocean. This process is called a biological pump. Therefore there is a relationship between the biological pump and the amount of ocean storage of CO_2. Maintaining this pump is crucial to help decrease the amount of CO_2 in the atmosphere. To summarize, the process of ocean acidification is greatly affecting the primary productivity which in turn, is causing a domino effect throughout the food chain, all the way up to the blue whales (keystone species), and threatening the existence of the entire marine ecosystem.

Effect of ocean acidification on soft shell formation of animals: The US Environmental Protection Agency (EPA)[27] warns that changing ocean chemistry will 1) harm life forms that rely on calcium carbonate-based shells and skeletons, 2) harm organisms sensitive to acidity, and 3) harm organisms higher up the food chain that feed on these sensitive organisms. Ocean acidification is negatively affecting the number of carbonate ions in the ocean. Carbonate ions are used to form calcium carbonate, the main component of shellfish such as oysters, crabs, clams, and scallops. Lack of desired amounts of CaCO3 also affects the formation of eggshells, snail shells, seashells, pearls, and the shells of some soft-shelled animals that live in the oceans. Just as humans need carbonate ions to build their bones, several plants and animals that live in the oceans need to form calcium carbonate to build their shells and skeletons. Sometimes the shells are formed slowly and other times they get dissolved faster as compared to the time it takes for them to form. Thus the increasing acidity of the seawater has devastating effects on the survival, growth, and reproduction of these organisms[28] .

The ocean acidification process is often referred to as the osteoporosis of the sea. It is causing the shells and skeletons of marine organisms to become thinner, more brittle, and endangering the health and survival of these organisms. This process is also disrupting the marine food chain and damages could be traced throughout the marine ecosystem. Ocean acidification is also leaving these plants and animals vulnerable to predators and affecting their health and survival. The acidity is negatively affecting the survival of the larvae of several species. This process, if unchecked soon, could result in the extinction of marine plants and soft-shell-forming animals. Ocean acidification is negatively affecting fish, crabs, squid, oysters, and other marine animals too. The excess of carbonic acid is known to cause acidosis. This process is affecting the life processes such as respiration, growth, reproduction, development of larvae, echolocation, and the basic survival of these marine organisms. If this trend continues, then it could affect the predator-prey relationships in the oceans across the globe. It could also lead to the extinction of several species if they are unable to evolve and adapt to these new changes. Lastly, this could have devastating effects on the commercial fishing/seafood industries and the world economy.

Effect of ocean acidification on the coral reef ecosystem: Ocean acidification is one of the key threats to coral reefs[29] as it reduces the calcification rate of reef framework builders. The acidity and decrease in carbonate ions are known to negatively affect the symbiotic relationships between the corals and the dinoflagellates that live in them. Scientists conducted experiments to see how ocean acidification affects coral reef-building organisms. The results from these studies revealed that the decrease in the pH of the oceans negatively affects coral survival, growth and calcification process, and their reproduction. It also causes the dinoflagellates to leave the coral resulting in coral bleaching[30] . Some scientists believe that coral bleaching could be reversed by decreasing the acidity of ocean waters.

It is promising to note that decreasing the amount of CO_2 in the atmosphere could halt the process of ocean acidification and prevent coral bleaching. This demonstrates that we should as a collective should come up with strategies to decrease the carbon dioxide (CO_2) released into the atmosphere. This could result in slowing down the global warming and ocean acidification process. The lesser the amounts of carbon dioxide (CO_2) in the atmosphere the lower the absorption of CO_2 by the oceans. This will in turn slow down the process of ocean acidification and in the process saving the plants, soft-shell-making organisms, the phytoplankton, coral reefs, and the entire marine ecosystems. This step could also help the biodiversity of our oceans, promote the fishing and seafood industry, local tourism, and prevent the mass extinction of marine organisms. According to the National Oceanic Atmospheric Administration (NOAA)[31] , ocean acidification, paired with the changes in the ocean temperatures are causing stresses on ocean life and the entire marine ecosystem. Ocean acidification has the potential to negatively impact the entire marine ecosystem and will certainly impact the fishing industry, tourism, and global economies. An overview of the marine ecosystem will try to explain how ocean acidification is affecting the producers as well as the consumers that are a part of this system.

The unit has the potential to inform the readers about the phenomena of the carbon cycle and ocean acidification. Understanding the concept of ocean acidification and how it is contributing to the decreasing of the pH in our oceans. Lastly, how this process is negatively affecting the plants, the shell-forming organisms, and the marine ecosystems. Some of the devastating effects include soft shell-forming organisms' survival is threatened due to the weakening of their shells, affecting the primary productivity of the marine ecosystem, negatively effects the plants and animals that make up the marine ecosystem, loss of habitat, loss of diversity, coral bleaching, and extinction of marine life. The modeling of the carbon cycle, ocean acidification and its effect on fish and soft-shell forming organisms, and coral bleaching phenomena have the potential to not only help students understand these processes visually but also drive the concepts home. The students could be provided with opportunities to problem-solve and come up with strategies to mitigate, decrease, as well as reverse the harmful effects of ocean acidification. Students will have a chance to create awareness posters and share this information with friends. Lastly, allowing students to create awareness posters and write letters to their local representations about the harmful effects of ocean acidification in Connecticut[32] will create enthusiasm about addressing the phenomena of ocean acidification. This unit could be modified for elementary and middle school level students.

Teaching Strategies and Lesson Plan Structure

This unit will be taught over 2 weeks, a maximum of 5 blocks (90 minutes long). Students learn Ecology during the third marking period. This unit will be used as an enrichment activity. A couple of challenges about teaching this unit are: sticking to the duration dedicated for this unit while keeping up with the pacing set forth by the district. Upon successful completion, the author could make the necessary changes to the unit and reteach it to other classes.

Classroom Activities:

1. Carbon Cycle (1 block / 90 minutes)

Students will answer the following "do now" question: What do you know about the earth's carbon reservoirs? The five major carbon reservoirs are rock, atmosphere, oceans, terrestrial biosphere, and fossil fuels.

Learning objectives: Students Will Be Able To (SWBAT) understand that the carbon cycle is fundamental to making sense of environmental changes such as global warming and ocean acidification.

Materials and teacher-developed resources: Five pounds rice (or other small grain or material), cups or other containers for counting and weighing rice, scale, permanent marker, four gallon-sized plastic zip-top bags, five-quart or sandwich-sized plastic bags, a box with the dimensions 10 cm x 10 cm x 10 cm (this can be made from a 1/2 gallon paperboard milk carton, cut in half). meter stick, Carbon reservoir images.

Learning activities: For the first 10 minutes of class, the students will answer the "do now" questions. Then they will conduct the hands-on lab, Follow and Carbon for 40 minutes. During the lab, students will use the chart provided and identify the principal carbon reservoirs and determine the approximate amount of carbon storage in gigatons, where each grain of rice represents a gigatons of carbon. Students will work in 5 groups and focus on one carbon reservoir each (rock, atmosphere, oceans, terrestrial biosphere, and fossil fuels). They will then model the flow of carbon between the atmosphere and terrestrial biosphere, ocean, and the atmosphere, flow from fossil fuels (the burning of which releases carbon dioxide into the atmosphere) while using the *Average Annual Carbon Fluxes* chart. This activity will provide students with an understanding of the carbon cycle.

Homework: Students will review the carbon cycle by creating Story Boards with the main focus of tracing the movement of carbon between the atmosphere, land, and the oceans and other bodies of water. They will also take an online carbon cycle Edpuzzle quiz.

2. Ocean Acidification in a cup (1 Block)

Students will answer the following “do now” question: What is Ocean acidification?

Learning objectives: Students Will Be Able To (SWBAT) understand observe a demonstration and understand the concept of ocean acidification.

Materials and teacher-developed resources: Safety goggles, An acid-base indicator such as bromothymol blue, two clear plastic cups (10-oz), paper cups(3-oz), masking tape, plain white paper, permanent marker, baking soda, white vinegar, two Petri dishes to use as lids for the plastic cups, graduated cylinder, gram scale or measuring spoons.

Learning activities: This activity illustrates “how the diffusion of a gas into a liquid can cause ocean acidification. It also models part of the short-term carbon cycle—specifically the interaction between our atmosphere and the ocean’s surface”. When we create a carbon dioxide-rich atmosphere in a cup by adding baking soda (Sodium Bicarbonate) to water and then add vinegar (an acid) and observe the changes. During this reaction one can observe that when bicarbonate is added to water and then the acetic acid in vinegar converts the bicarbonate to carbon dioxide. Therefore, this model shows how carbon dioxide gas diffuses into the water, resulting in the formation of carbonic acid and in the process makes the water more acidic.

(aq) + H2O → H2CO3. Then the carbonic acid dissociates into hydrogen ions and bicarbonate ions. The increase in the hydrogen ions makes the water acidic. Students will observe the modeling demonstration and make qualitative and quantitative observations. They will write down the time it took for the acid-base indicator to change color on the worksheet provided. During the last 30 minutes of the class, they will have an open discussion about the information they collected, the cause and effects of ocean acidification, they will determine if the effects could be reversed, and how.

Homework: Students will complete the ocean acidification in a cup lab report.

3. Shells in Acid- Modeling Coral Bleaching and see why ocean acidification may be giving some marine organisms shell shock.

Students will work on the following “do now” question: What is Coral Bleaching? How does can it be prevented and reversed?

Learning objectives: SWBAT explores how the pH of a solution dictates whether carbon is present in the form needed to make seashells. A wide variety of ocean organisms—from shellfish and corals to certain kinds of algae—contain calcium carbonate in their exoskeletons. There needs to be a sufficient concentration of carbonate ions available for these creatures to construct their shells. The uptake of CO_2 in the ocean decreases the concentration of carbonate ions and pH in the oceans, a phenomenon called ocean acidification.

This phenomenon is affecting shell formation and coral bleaching.

Materials and teacher-developed resources: assorted seashells, vinegar, calcium chloride ($CaCl_2$, sold as Damp Rid in stores), sodium bicarbonate ($NaHCO_3$, also known as baking soda), 0.25 molar sodium hydroxide ($NaOH$, sold as lye in stores), several clear cups, water, permanent marker, safety goggles, pH indicators such as cabbage juice, bromothymol blue, or phenol red.

Learning activities: Students will observe a demonstration of the effect of ocean acidification on shell-forming organisms. They will be able to make observations and note down the changes in the cups when shells (primary components are calcium carbonate) are added to cups containing sodium bicarbonate solution (baking soda and water), calcium chloride solution, and vinegar.

Homework: Students will reflect on the lab and understand the negative effects of ocean acidification on shells and think about creative ways to mitigate this process. If I were a scientist, I would do the following to address/stop and reverse ocean acidification and coral bleaching. They will present their ideas to their peers during the next class.

4. Culminating Activity: Invention Convention Expo

Learning objectives: SWBAT will first have a chance to present their ideas to address ocean acidification to their peers. They will then work in groups of 4 and create awareness posters about ocean acidification and coral bleaching, including how they would address, decrease, stop, and reverse the processes.

Materials and teacher-developed resources: Posters, paper, pencils, markers, computer access.

Learning activities: Students will create awareness posters. They will also draft a letter to their local county/city representatives to grab their attention and create awareness about ocean acidification and coral bleaching. Given that the students are from New Haven and its surrounding towns this topic will help bring their attention to the importance of taking care of the Long Island Sound.

Appendix on Implementing District Standards

(Implementing the NGSS)

- HS-ESS 2-7: Construct an argument based on evidence about the simultaneous coevolution of Earth's systems and life on Earth.
- HS-ESS 2-6: Develop a quantitative model to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.
- HS-ETS 1-2 : Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.
- HS-ESS 3-6 : Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity.
- HS-ESS 3-4 : Evaluate or refine a technological solution that reduces the impacts of human activities on natural systems.

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Resources for students

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This image explains the process of the carbon cycle as well as the movement of carbon between the land, water bodies such as rivers and oceans, and the atmosphere.

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This document is created as a toolkit for local school boards. It highlights the Connecticut Next Generation Science Standards (NGSS-CT)

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NSTA. “Science and Engineering Practices.” NGSS@NSTA. Accessed March 29, 2021. https://ngss.nsta.org/PracticesFull.aspx.

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